TFAWS 2015

Thermal Coatings Seminar Series Training
Part 1 : Properties of Thermal Coatings

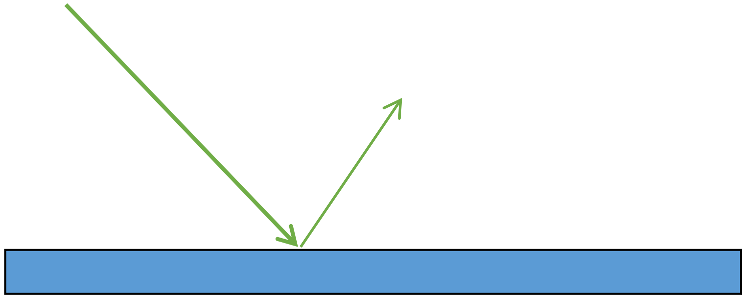
NASA GSFC Contamination and Coatings Branch – Code 546

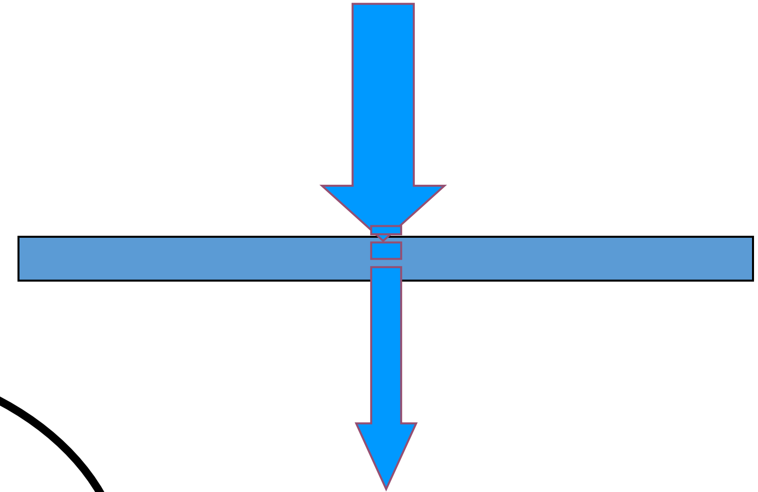
Hosted by: Jack Triolo - SGT, Inc.

Agenda

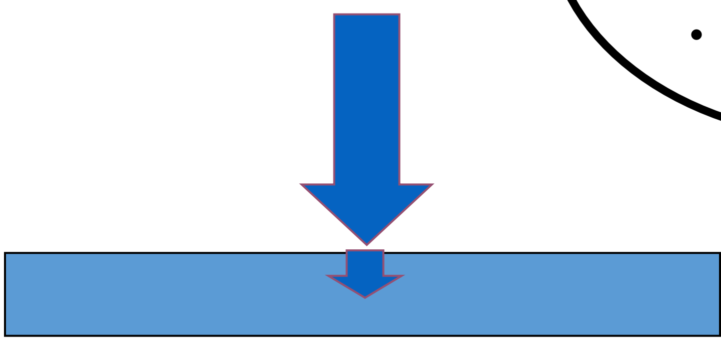
- The Relationship of Coating Properties That We Can "Easily" Measure vs. the Properties We Need…α_S & ε_H
- How Solar Absorptance is Determined
  - Description of Solar Reflectance measurement techniques
  - Typical data
- How Thermal Hemispherical Emittance is Determined
  - Conversion of normal emittance to hemispherical emittance
  - Emittance vs. temperature
  - Description of measurement techniques
  - Typical data
- Factors that Influence Thermal Radiative Properties
- BRDF – Specular and Diffuse
- GSFC Instruments Overview
- Types of Coatings Used at GSFC

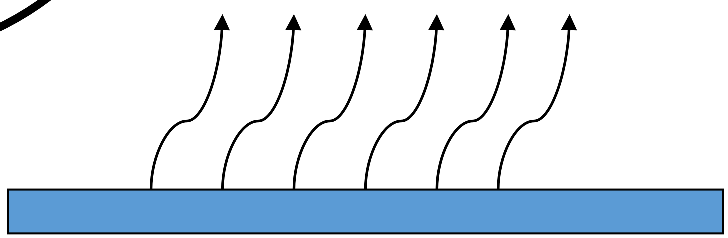
Thermal Radiative Properties of Coatings





- Reflectance
- Transmittance
- Absorptance
- Emittance





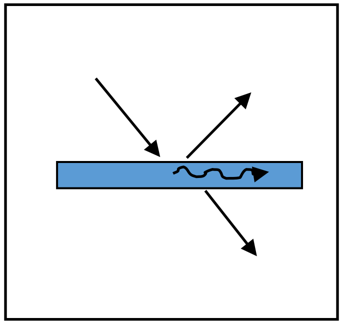
Thermal Radiative Properties of Coatings

(Information Obtained From Thermal Radiative Properties Coatings, Thermaphysical Properties of Matter, Volume 9)

- Radiant energy is reflected, transmitted and/or absorbed by a surface or material

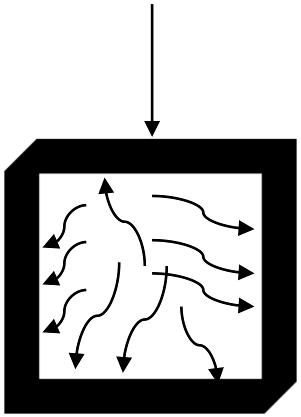
  r + t + a = 1, for materials, where t = 0, r + a = 1, or a = 1- r

  Where: Reflectance = r, Transmittance = t, and Absorptance = a



- Emittance (e) is the rate at which a body radiates energy (heat) at a given temperature in relation to the rate a black body radiator radiates energy (heat) at the same temperature
- Kirchhoff's Law
  - Ideal radiator, when in thermal equilibrium, the body emits radiant energy at the same rate at which it absorbs

$$\alpha = e$$



- In the Aerospace Industry, a and e are never directly measured – THEY ARE CALCULATED!

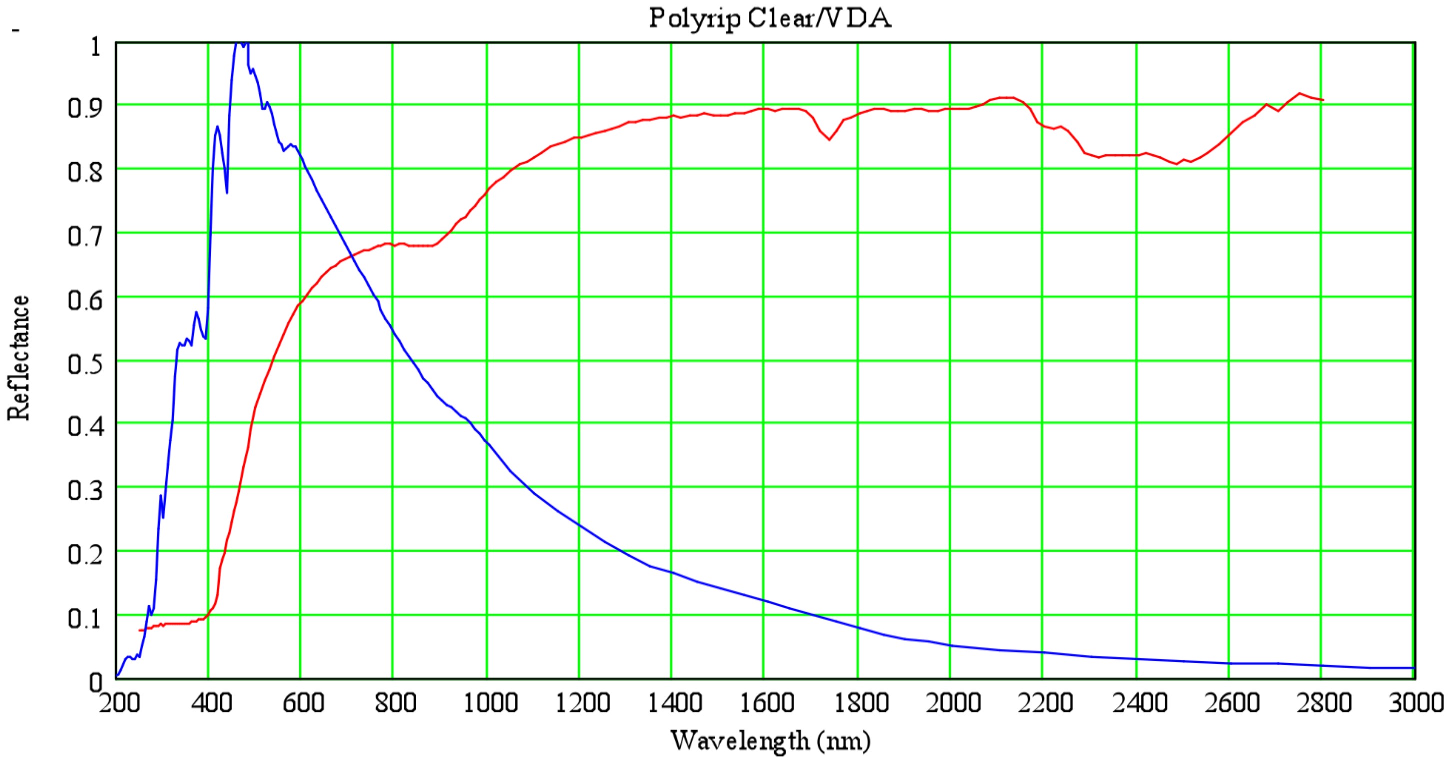
Solar Absorptance Property Measurement

- At GSFC, the instrumentation used to calculate the solar absorptance measures over the spectral range of 250 to 2800 nanometers (.25 to 2.8 microns). An integrating sphere is used to measure the coating's reflectance for the solar absorptance calculation
- Solar Absorptance is the total solar energy absorbed by the surface divided by the total solar energy integrated as a function of the wavelength

$$\alpha_s = 1 - \frac{\int_{250}^{2800} R(\lambda)\cdot S(\lambda)\,d\lambda}{\int_{250}^{2800} S(\lambda)\,d\lambda}$$

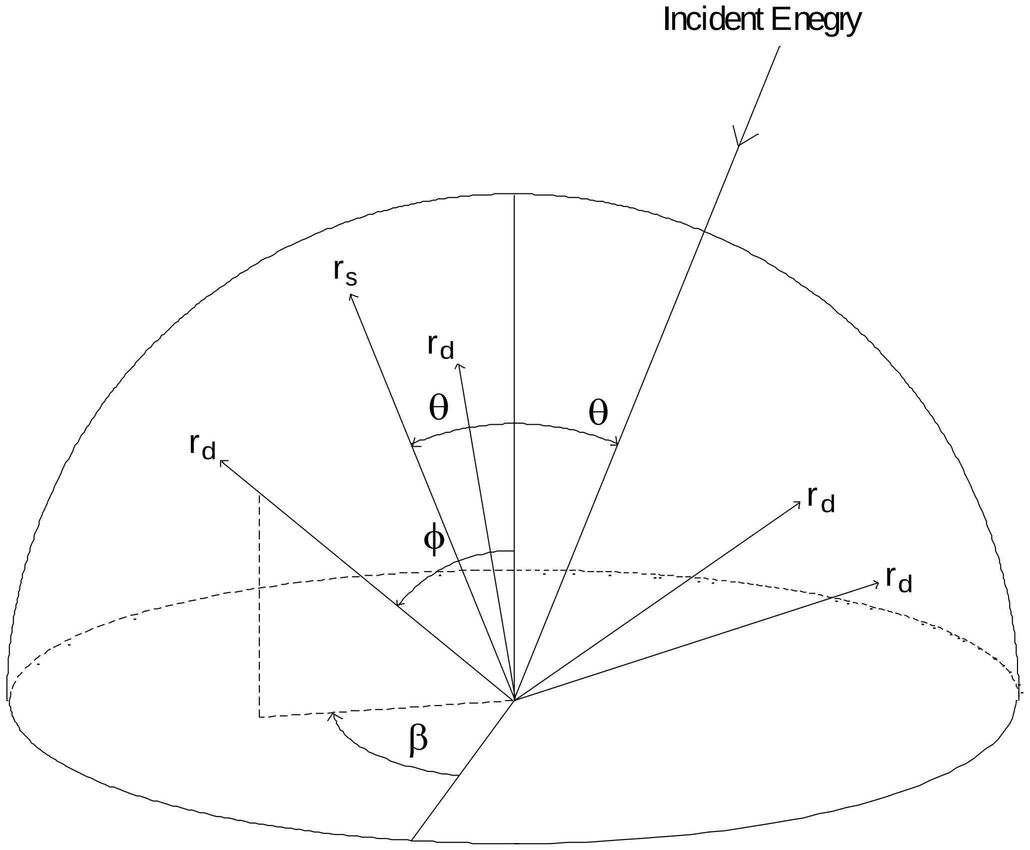
- Where R = reflectance, S = solar energy, a_s = solar absorptance, and l = wavelength
- The reflectance measurement is performed near-normal (angle of incidence = 15°). This measurement is typically sufficient for most surfaces up to approximately 45°
- Whereas, when measuring cylindrical surfaces, spherical surfaces or angle of incidence greater than 45°, variations in the angle of incidence will influence the solar absorptance value and must be measured
- Typically the Johnson curve is used to represent the total solar energy over the solar spectrum

Reflectance and the Johnson Curve

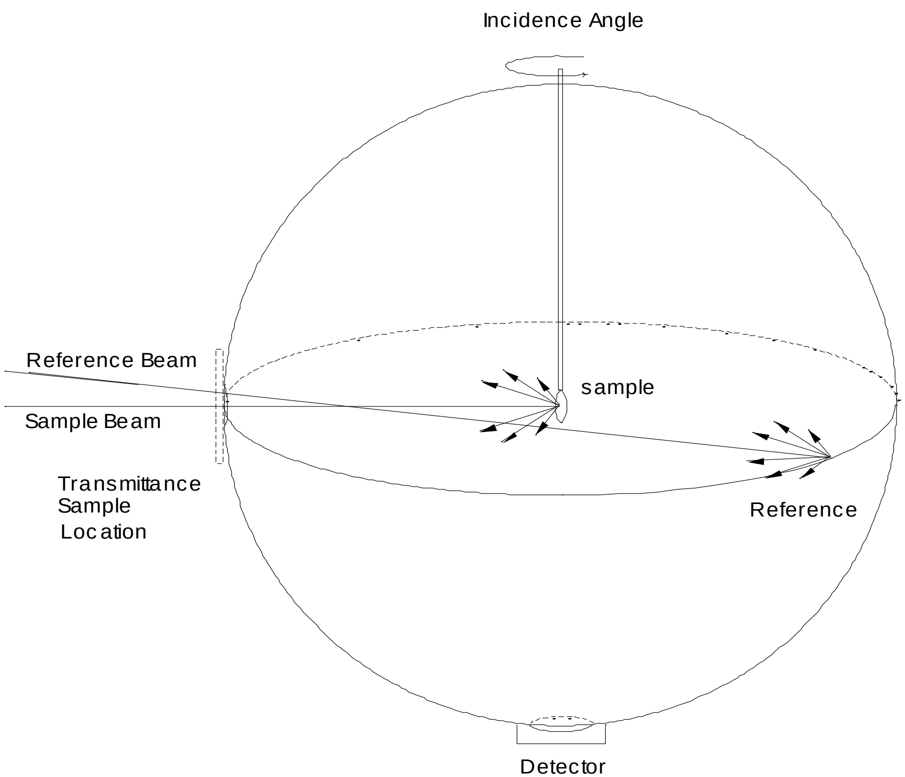


Johnson curve (blue) and the Polyrip clear/VDA (red)
Solar Absorptance value = .405

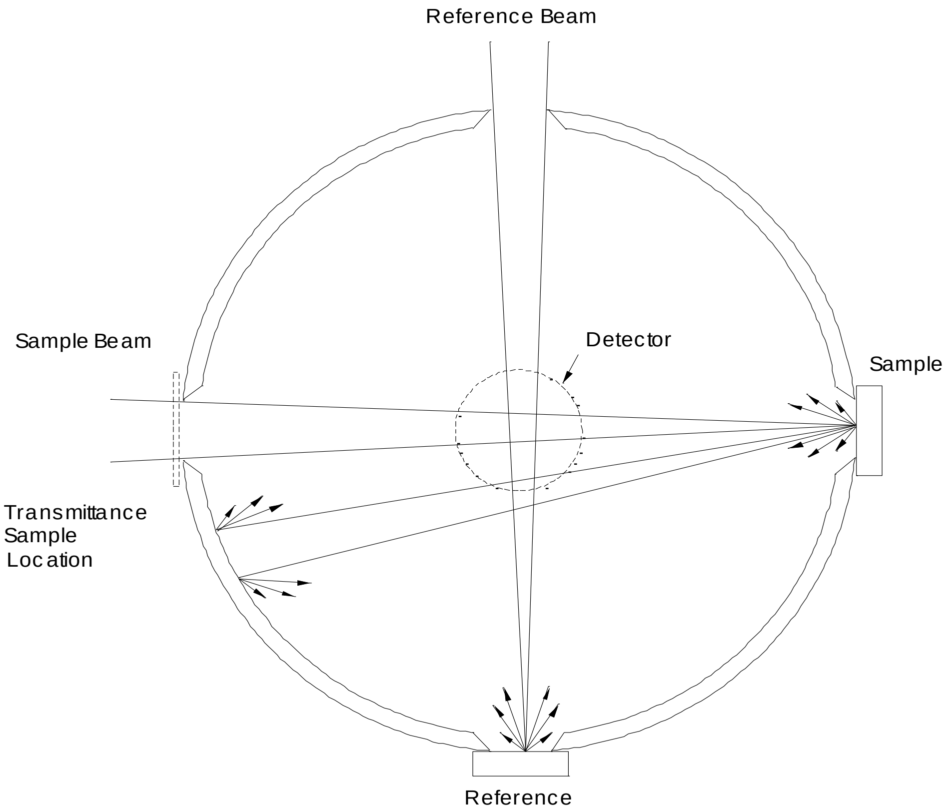
Directional Total Reflectivity



Two Types of Integrating Spheres

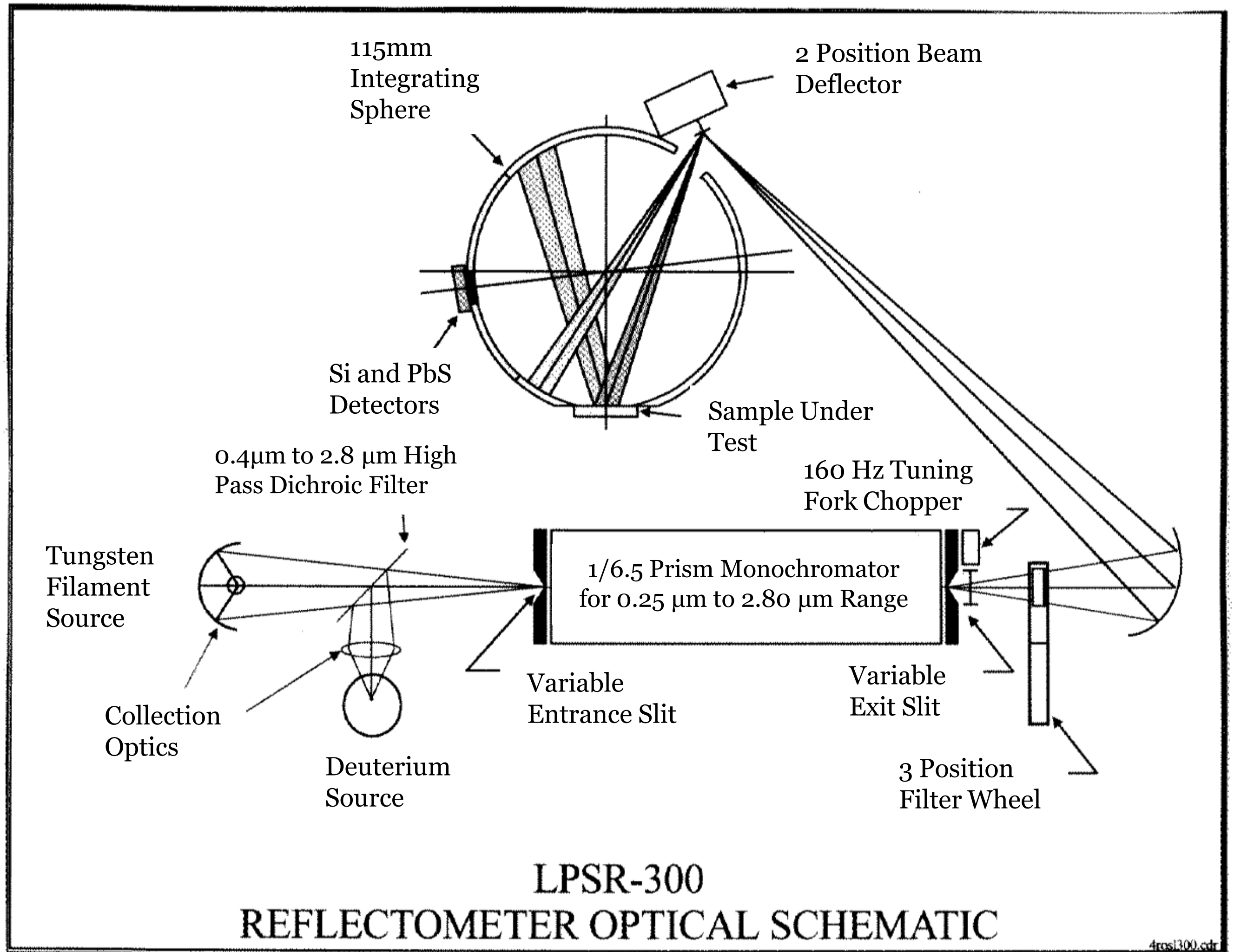


Edwards Type Integrating Sphere

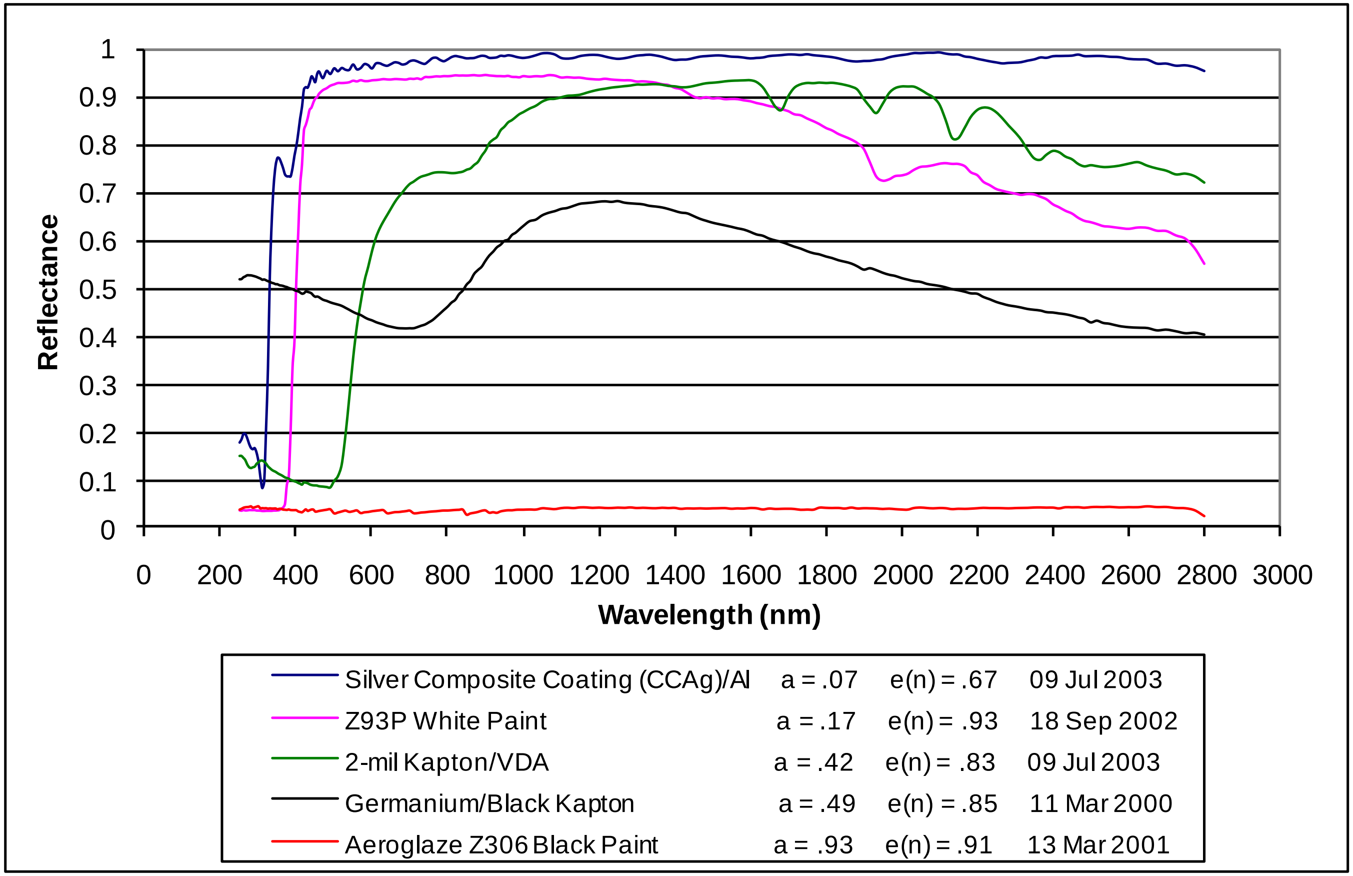


Four Port Comparsion Integrating Sphere

LPSR-300 Reflectometer Optical Schematic



Reflectance Curves of Various Thermal Coatings



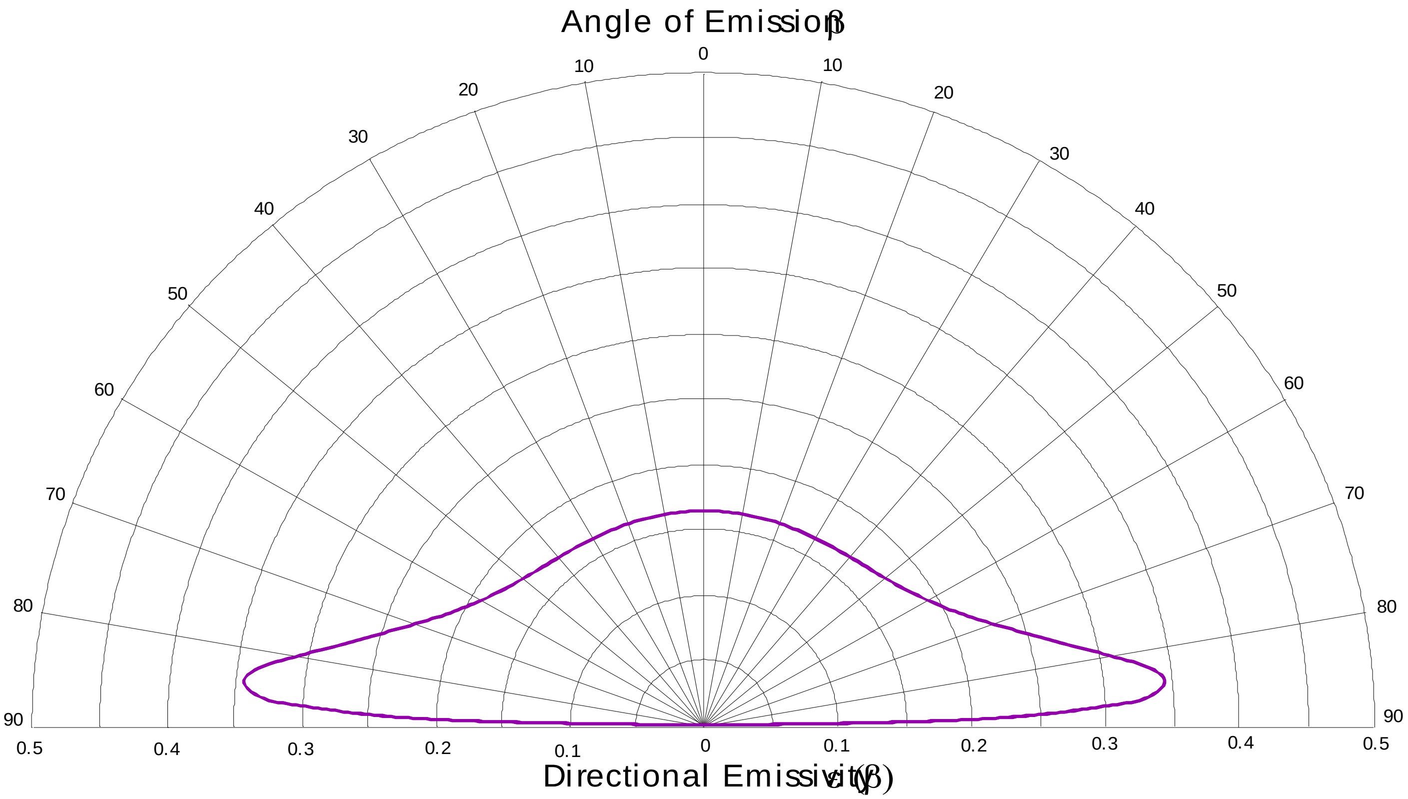
Emittance Property Calculation

- Normal Emittance
  - At GSFC, the instrumentation used to calculate the normal reflectance measures over the spectral range of 5 to 100 microns at room temperature
  - The normal emittance is calculated by measuring the reflectance of a material's surface in the infrared region of the spectrum and subtracting the measured reflectance from one (for opaque coatings only)

$$\varepsilon_N = 1 - \frac{\int_0^\infty R(\lambda)B(\lambda)d\lambda}{\int_0^\infty B(\lambda)d\lambda}$$

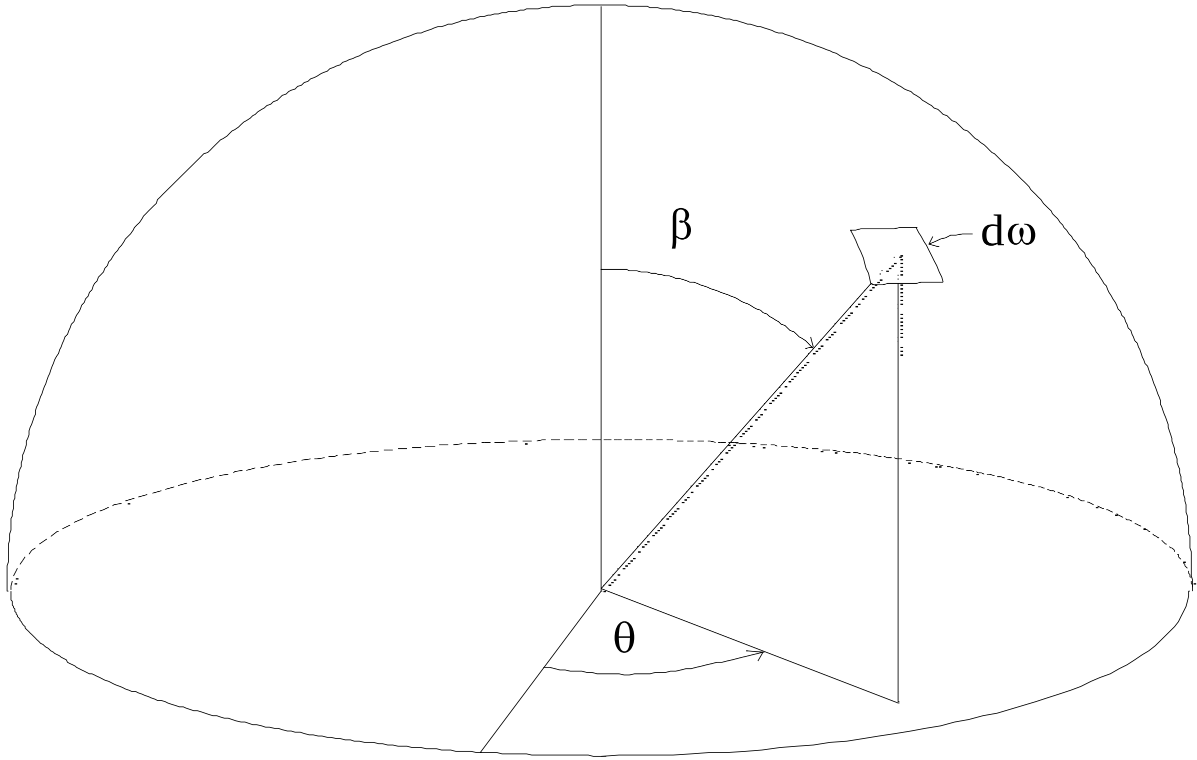
- Hemispherical Emittance
  - For thermal modeling and analysis, the emittance must be in terms of a hemispherical (total body) emittance value. Converting normal emittance to hemispherical emittance can be accomplished by using a conversion table and chart by E. Schmidt, E. Eckert, and M. Jakob
  - Hemispherical emittance can also be determined by calorimetric emittance measurement
  - With the addition of an ellipsoidal attachment, GSFC also has the capability of calculating hemispherical emittance as a function of temperature by radiometric reflectance measurement

Directional Emissivity Curve For a Conductor



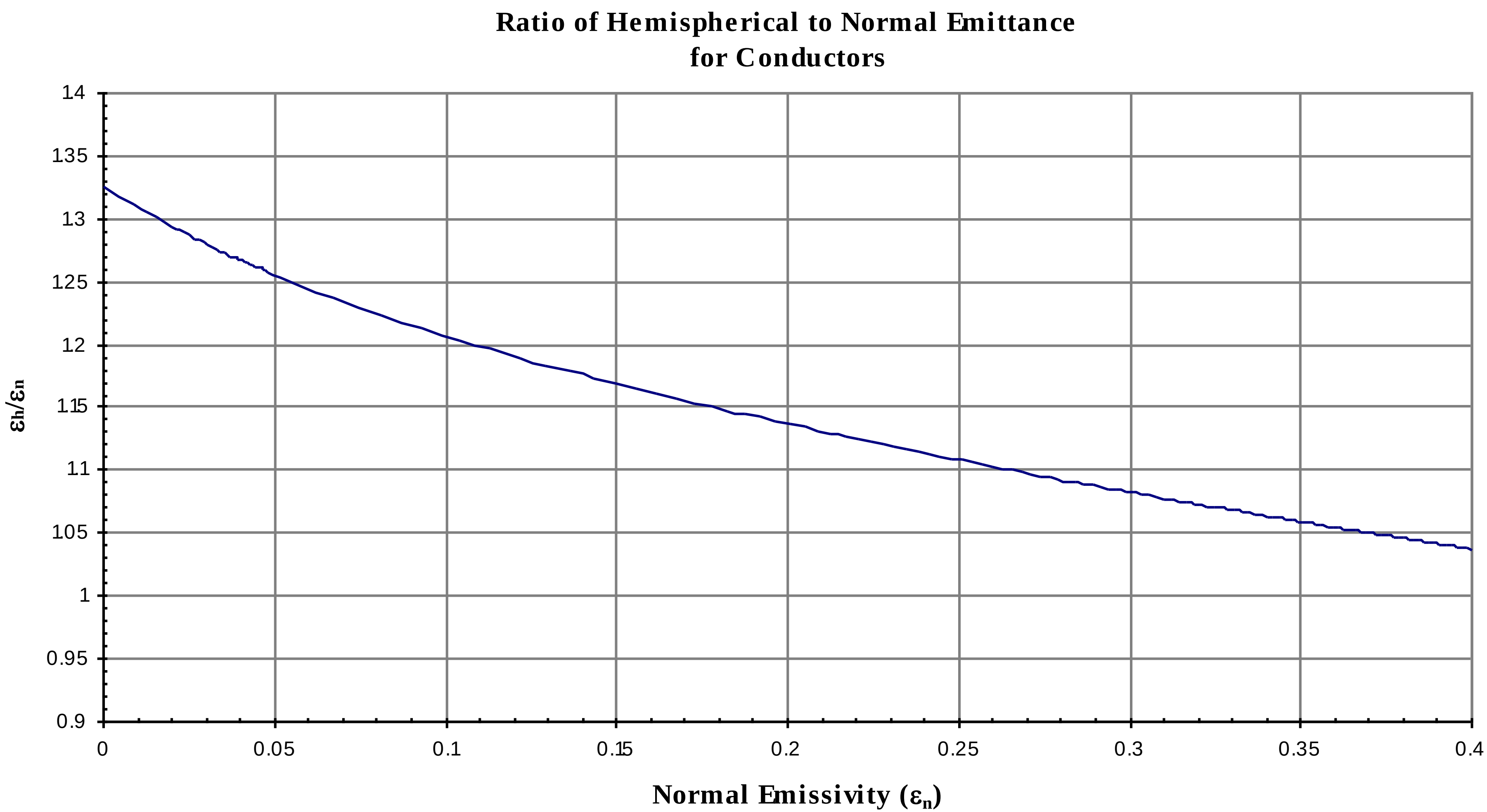
Directional emissivity curve for a conductor with an index of refraction of n= 5.7+i9.7

Hemispherical Emissivity Coordinate System

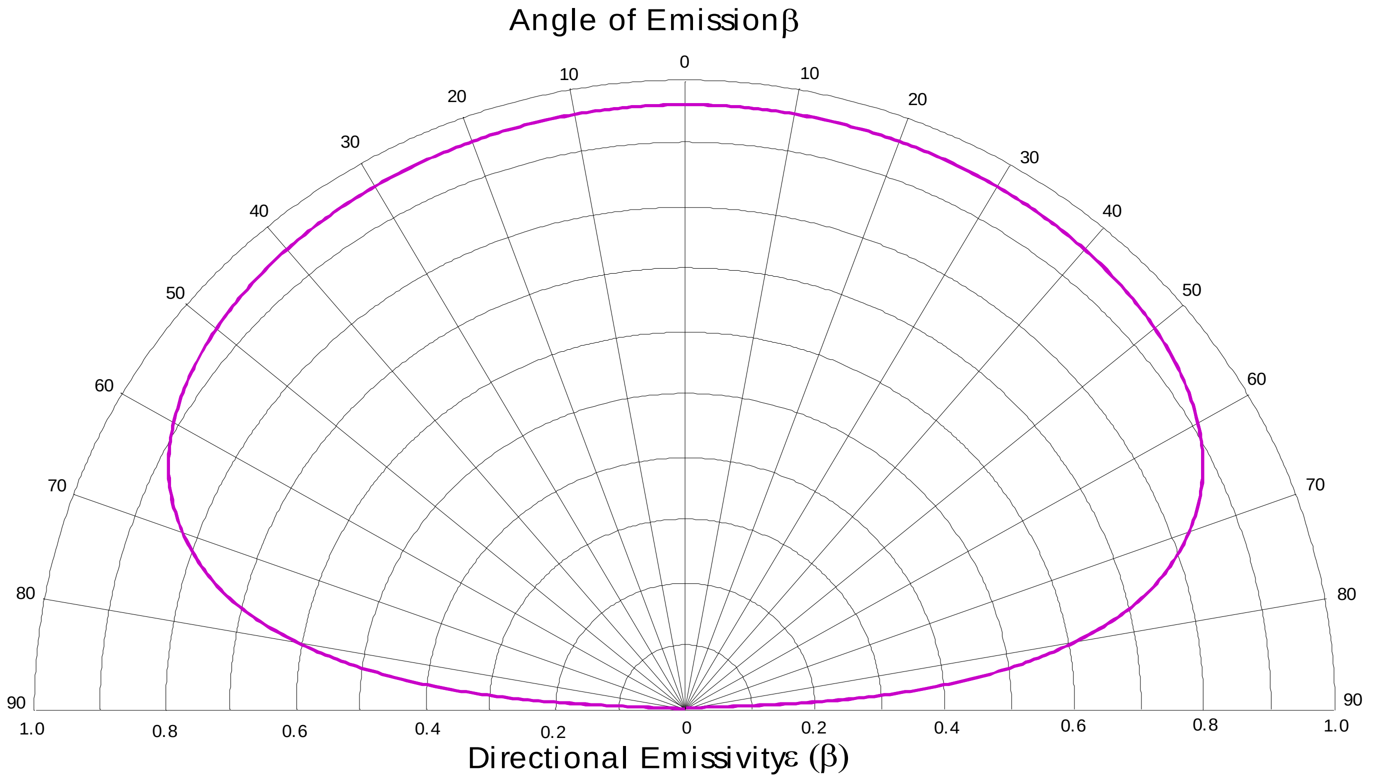


$$\varepsilon_H = \frac{1}{\pi}\int_0^{2\pi} \varepsilon(\beta,\theta,)\cos\beta d\omega$$

Ratio of Hemispherical to Normal Emissivity for Conductors

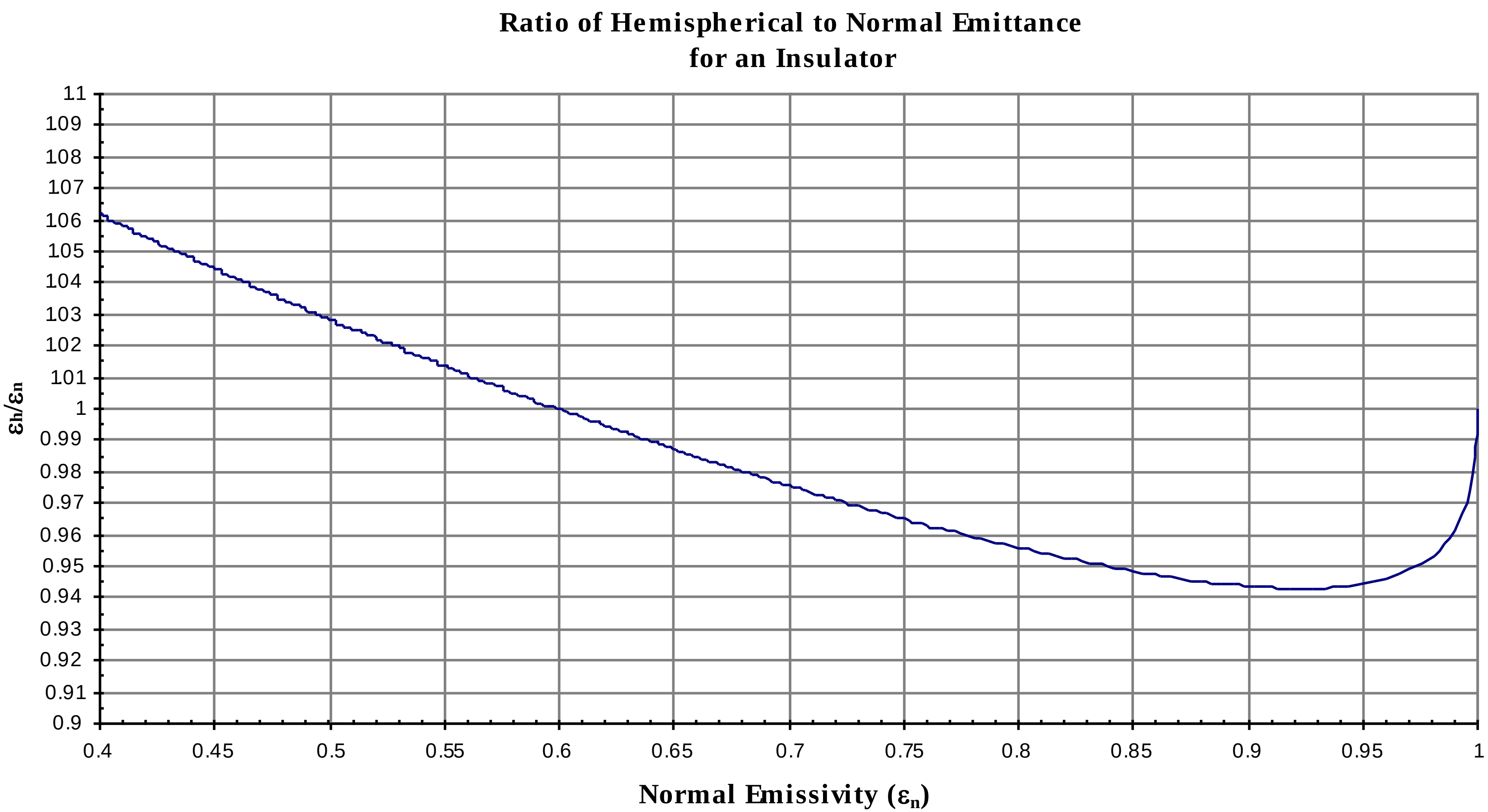


Directional Emissivity Curve for a Dielectric

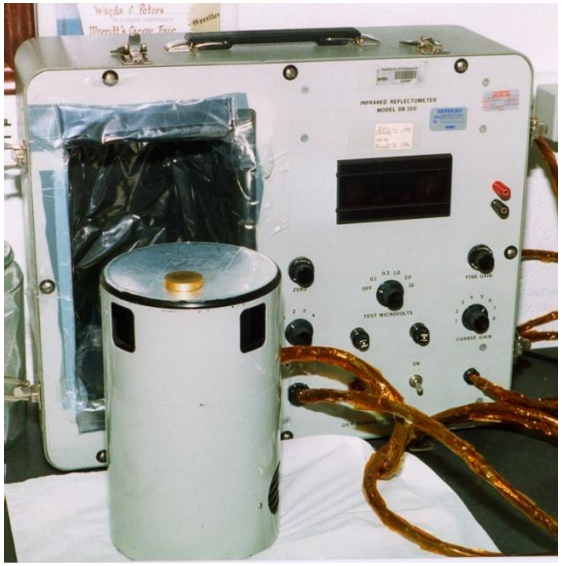


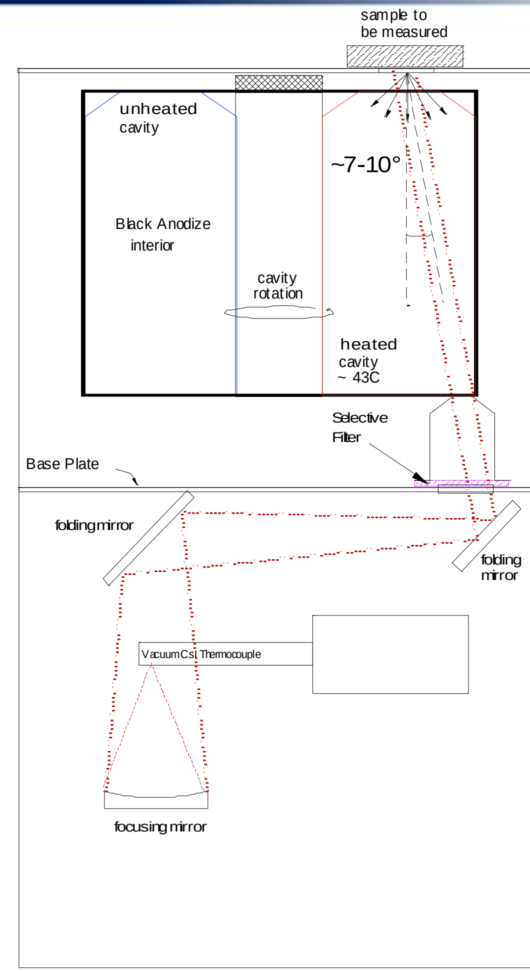
Directional emissivity curve for a dielectric
with an index of refraction of n=1.5

Ratio of Hemispherical to Normal Emissivity for Insulators

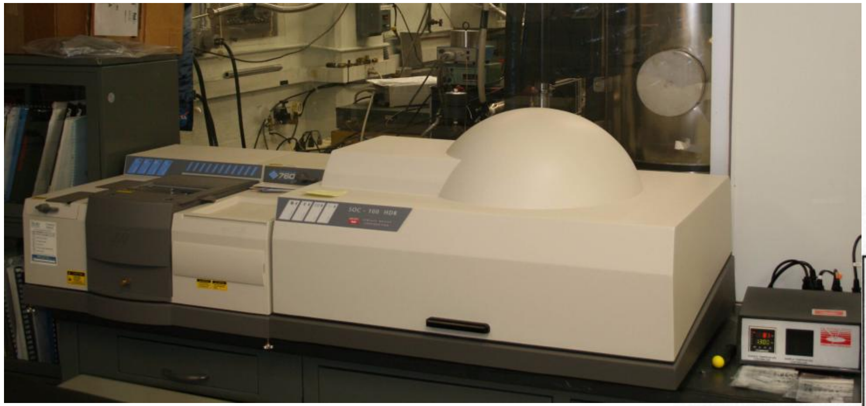


DB 100 Optical Diagram





Illumination: Hemispherical
Detector: Directional ~7-10 deg
Detector type: CsI vacuum thermocouple
Detector Range: 5?-40μm?
Accuracy: ±0.02 sample must be gray
Measurement: Hemispherical-Directional Reflectance



Illumination: Hemispherical
Detector: 10˚ -80˚
Detector type: FTIR: Si, KBr, Pe
Detector Range: 2-100μm
Accuracy: ± ?
Measurement: Hemispherical-Directional Spectral

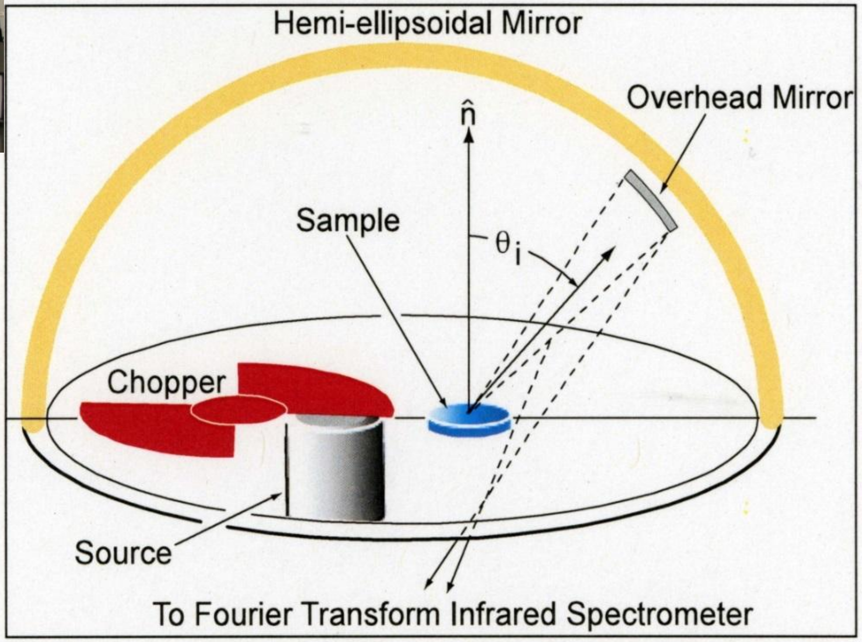
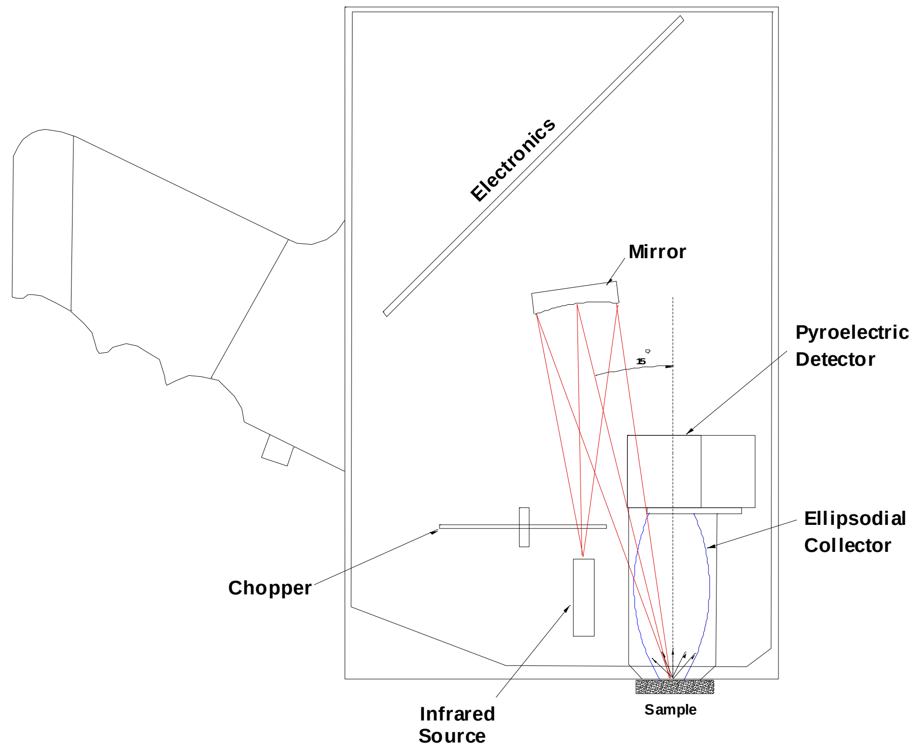


Figure 19: SOC-100 HDR Internal Layout.

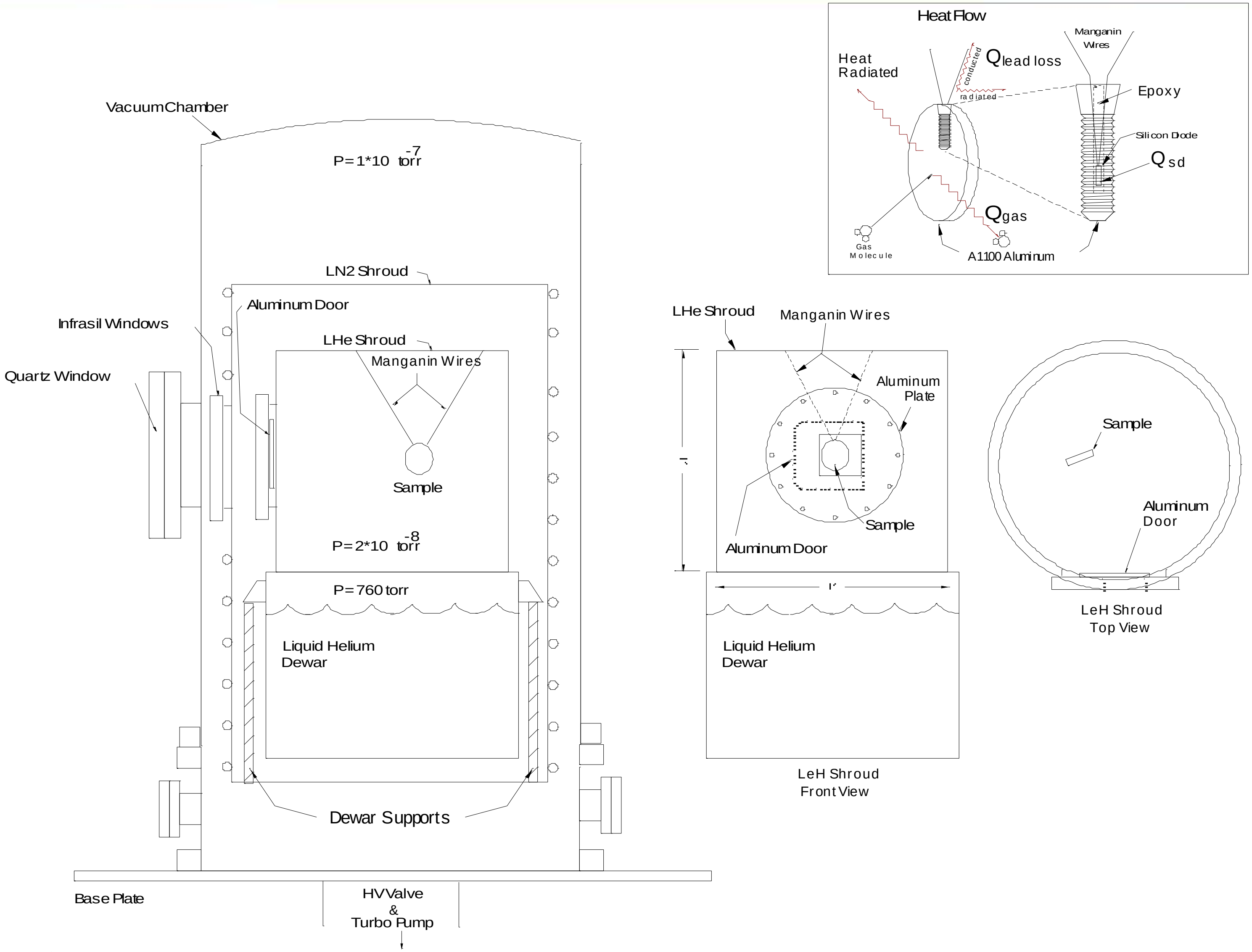
Temp200A Optical Diagram



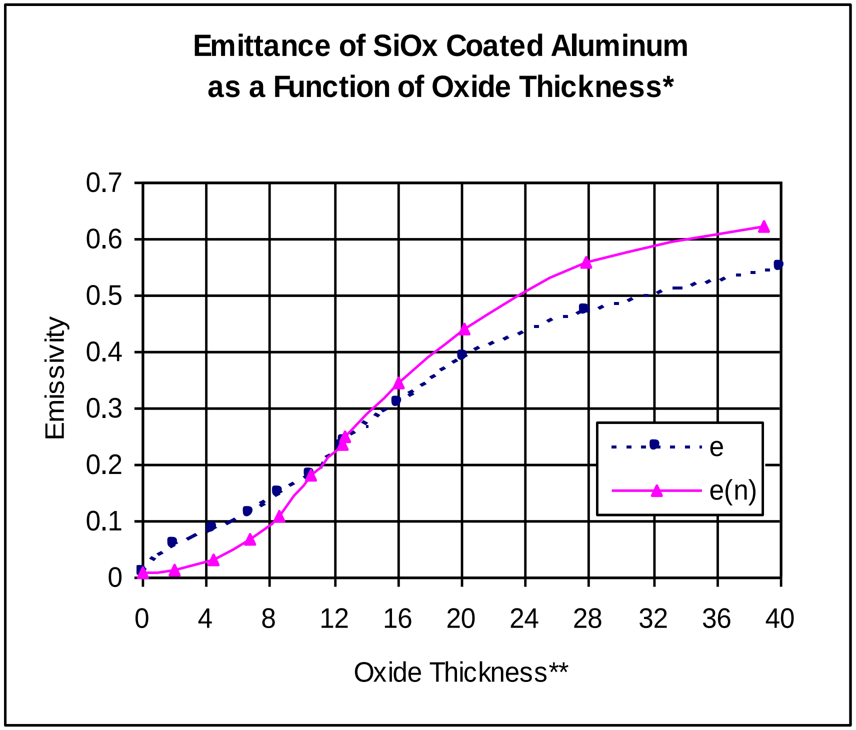
Temp 2000A Optical System

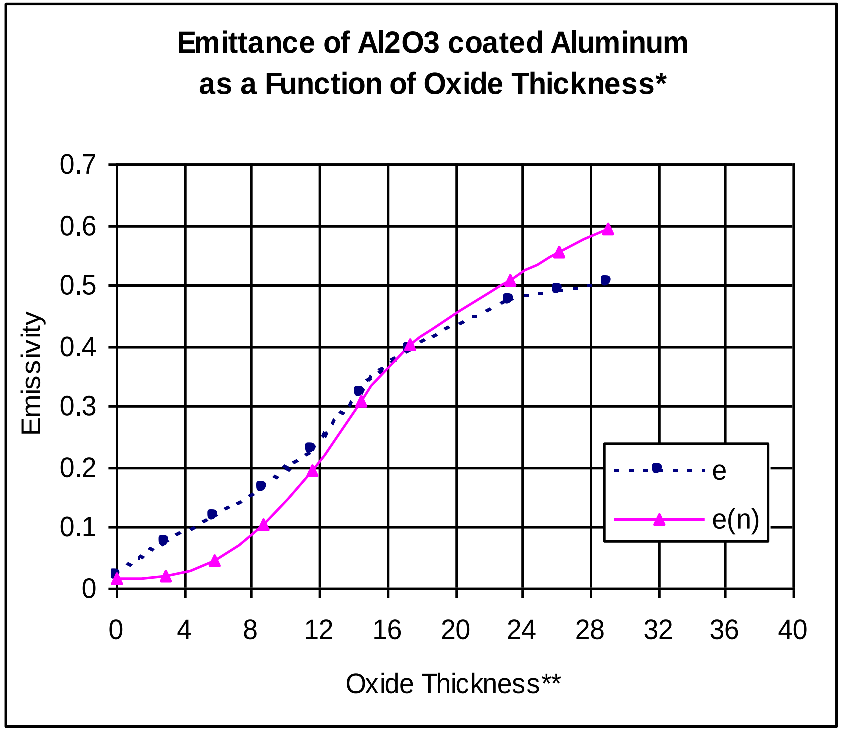
Illumination: 15°
Detector: Hemispherical
Detector type: Pyroelectric
Detector Range: 3-35µm
Accuracy: ±0.01 for gray samples
±0.03 for non-gray samples
Measurement: Directional-Hemispherical Reflectance

Emittance by the Calorimetric Technique



Dielectrics over Metals





* **Charts reproduced from Heaney, Triolo, and Hass, "Evaporated Thin Films For Spacecraft Temperature Control Applications", July 1977.**

** **Oxide Thickness is represented as $\lambda/4$ at 550 nm.**

Spectral Reflectance

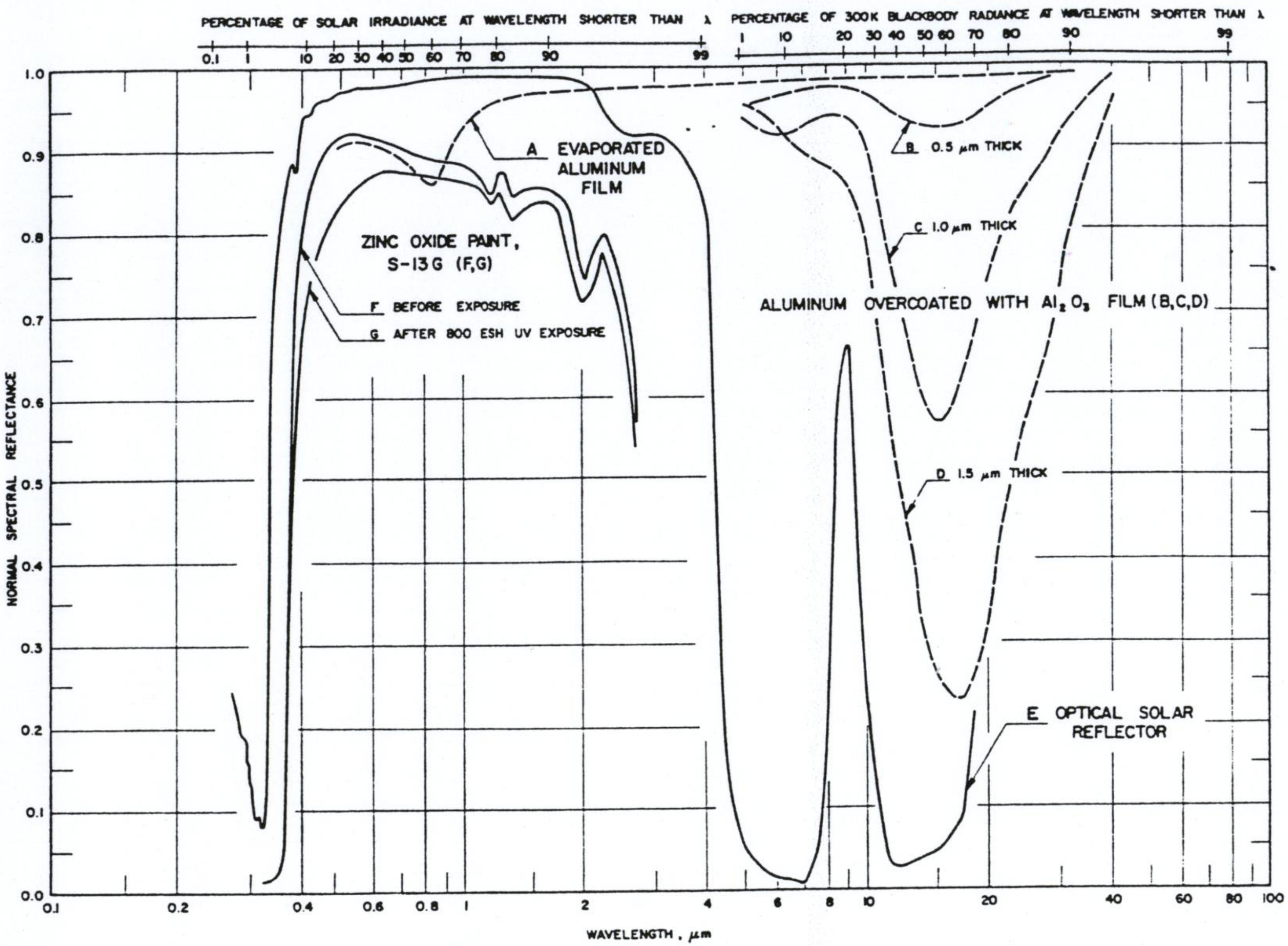


Fig. 7. Typical spectral characteristics of selected coatings: *A*, evaporated aluminum, *B*, *C*, and *D*, evaporated aluminum over-

Blackbody Spectral Radiance

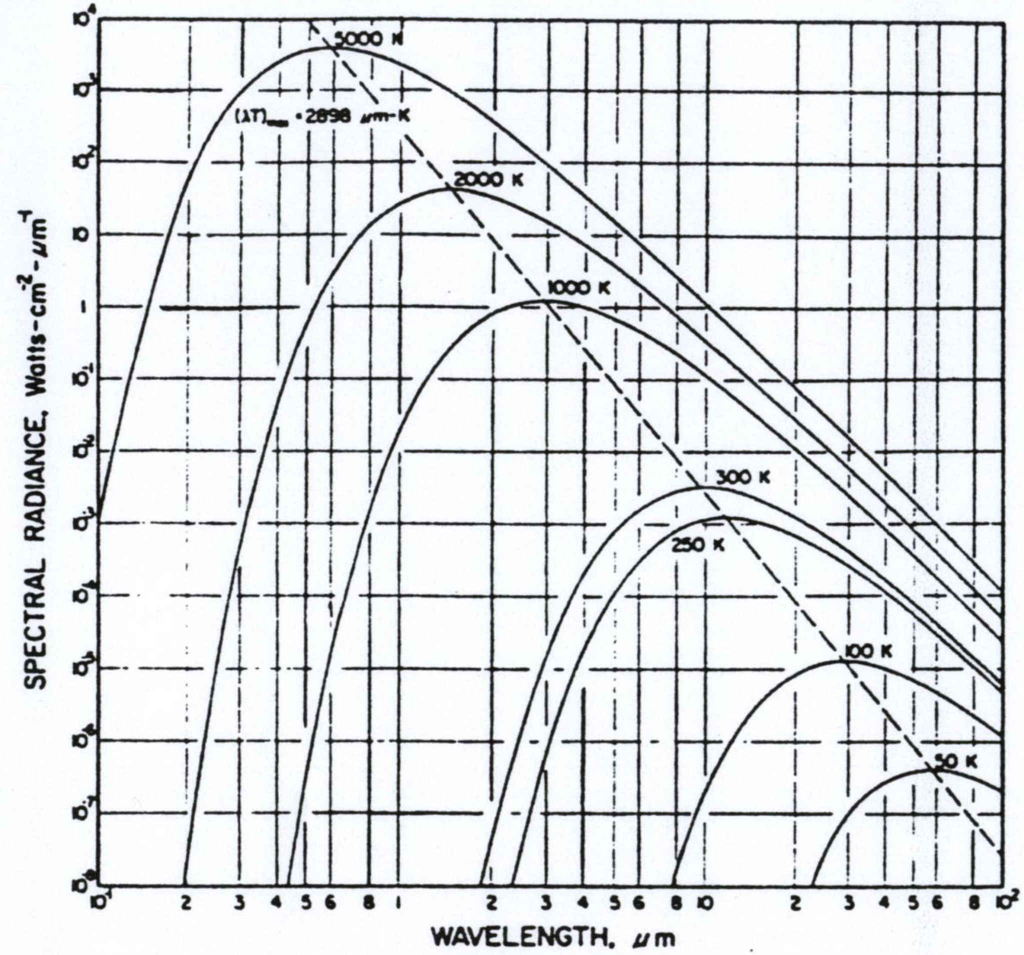
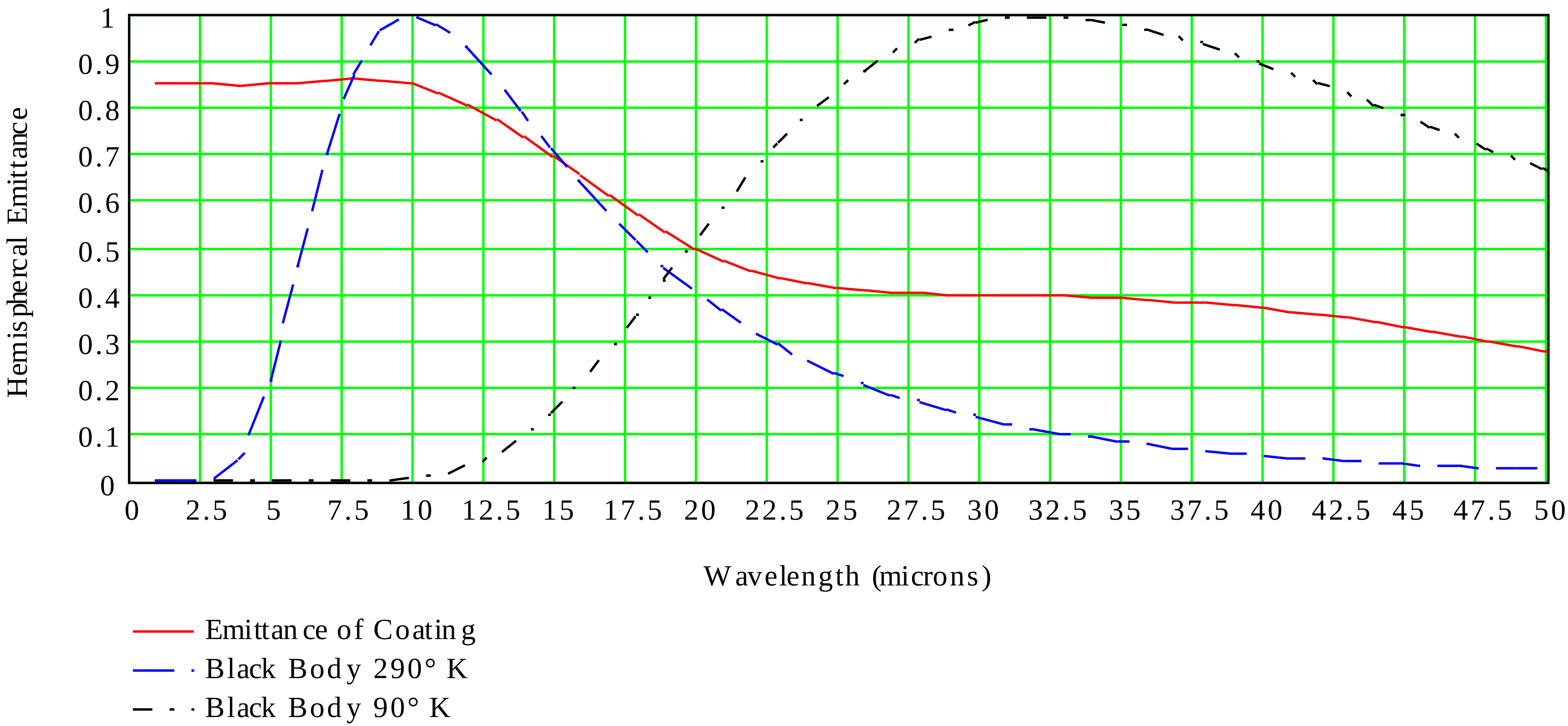
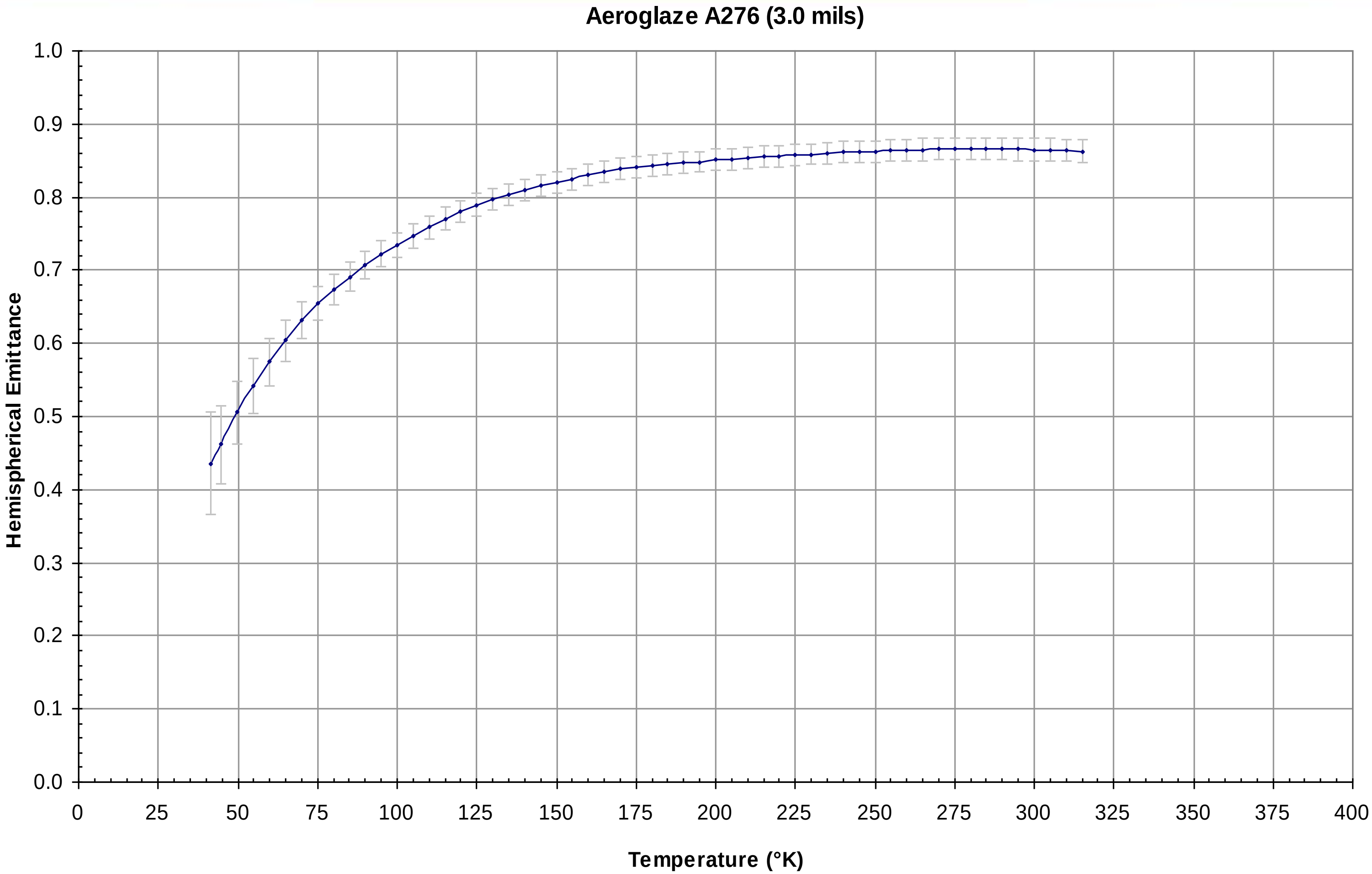


Fig. 1. The Planck distribution law, spectral radiance of blackbody radiation as a function of temperature and wavelength.

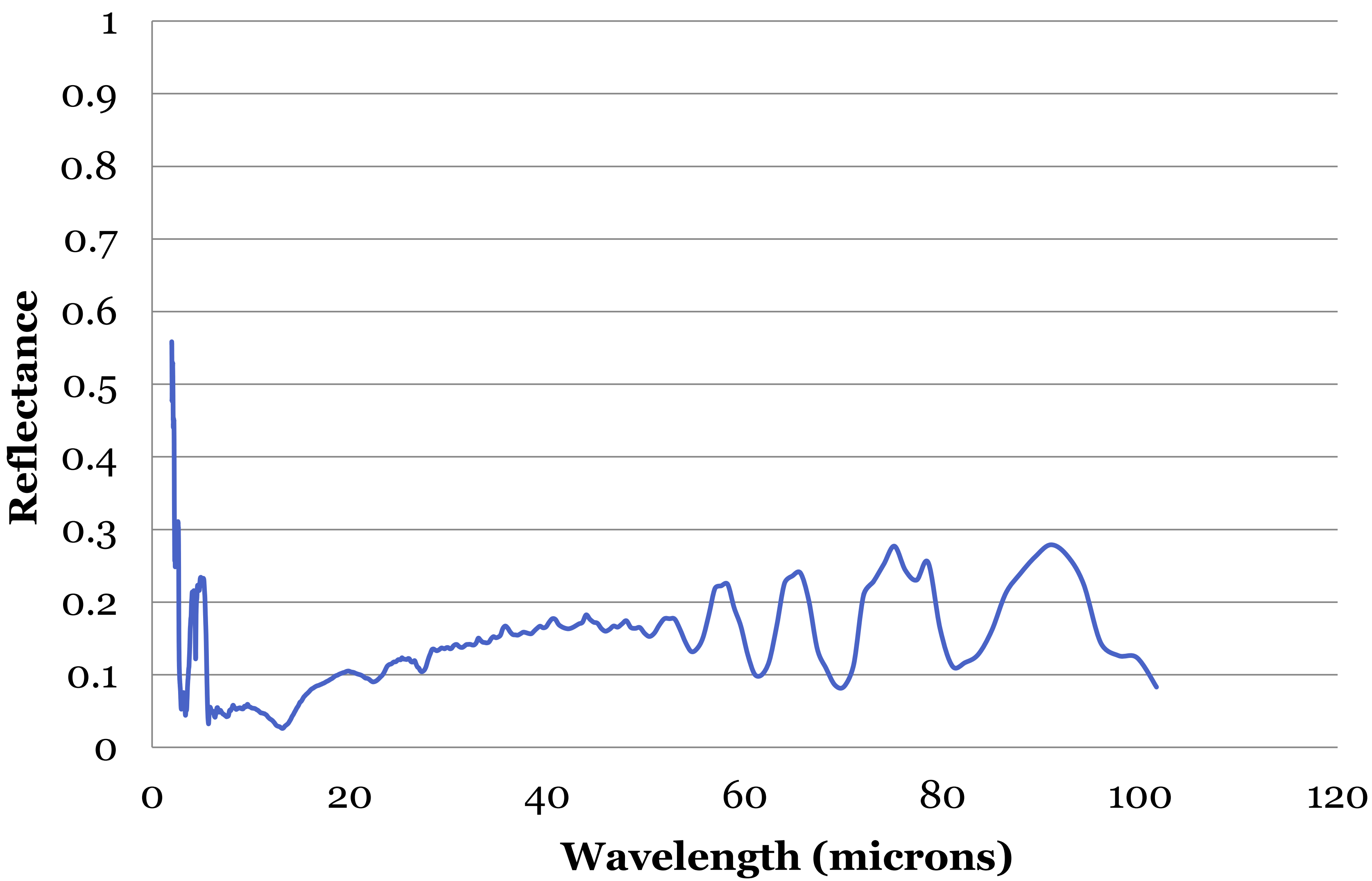
Emittance of a Hypothetical Coating and Two Black Body Temperature Curves



Calorimetric Results for A276



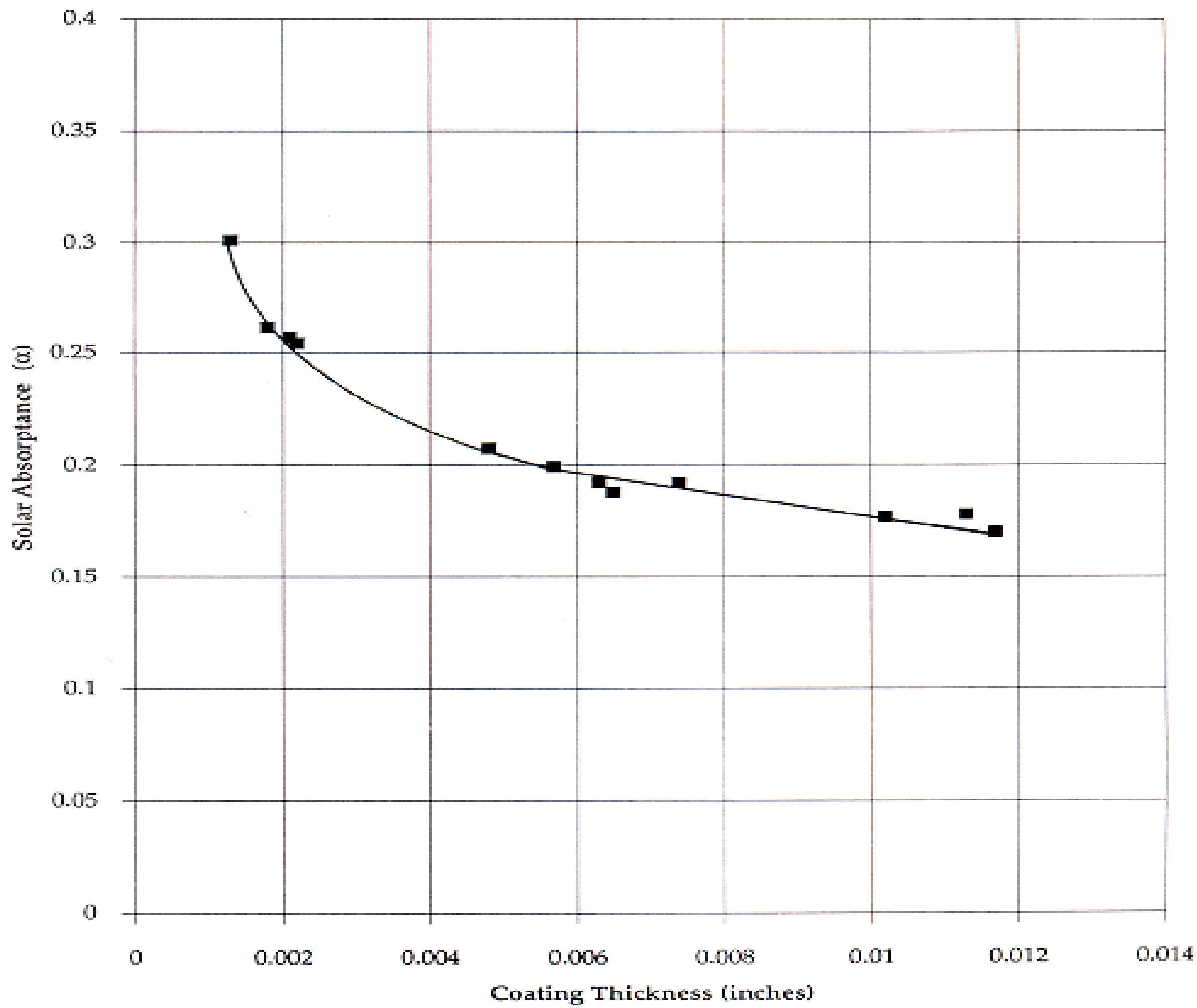
Infrared Reflectance of A276



Factors that Influence Thermal Radiative Properties

- Solar Absorptance and/or Emittance Values Influencing Factors:
  - Surface Finishes
    - Highly Polished (mirror-like/optical surface)
    - Polished
    - Buffed
    - Matt
    - Machined
  - Substrate Texture
    - Rough versus Smooth
    - Woven
    - Bead Blasted (sand, glass, etc…)
  - Immersion Rate for Chemical Coatings Processes (i.e., Anodized, Irridited)
  - Coating Thickness
  - Coating Adherence
  - Transmissivity
  - Electrical Conductivity
  - Contaminants
  - Sample/Hardware Size and Configuration

Solar Absorptance of a White Silicone Paint as a Function of Thickness



NASA-GSFC Thermal Control Coatings Measurement Instrumentation

- AZTek Laboratory Portable Spectroreflectometer (LPSR-300 and LPSR-200)
- Cary 500 IR/Vis/UV Spectroreflectometer
- Geir-Dunkle DB-100 Reflectometer
- SOC-100 Infrared Spectroreflectometer (2μ - 100μ)
- Bi-Directional Reflectance Distribution Function (BRDF)
- Light Analyzer Microscopic Imager
- Calorimetric Emittance Chamber





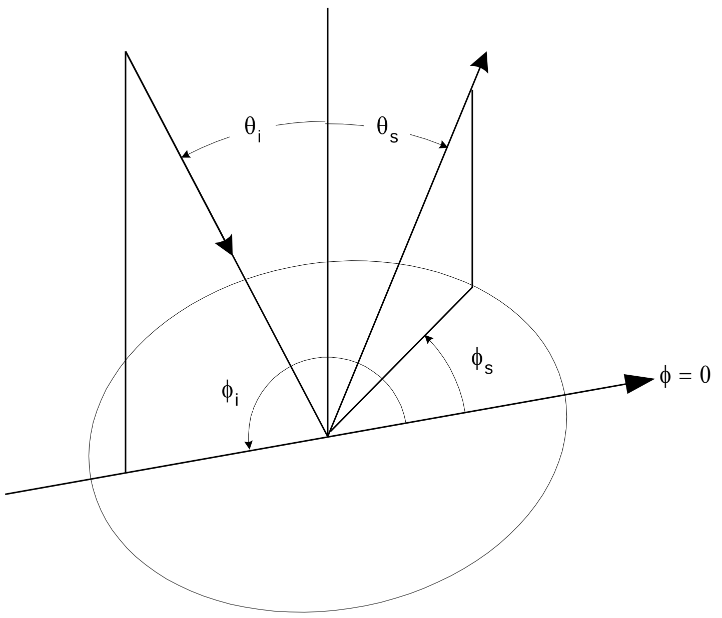

Bi-directional Reflectance Distribution Function

- BRDF is a precise measurement of the intensity and direction of the reflection of light from a surface

$$\frac{\text{Power reflected per unit area per solid angle}}{\text{Power arriving per unit area } \mathbf{X} \ \cos(\theta_s)}$$

- BRDF is a point property of a surface. BRDF is a function of the direction of the incident light and the direction of the scattered light

- Our facility has the capability to measure light scattering at 632.8 nm, 442 nm, and 830 nm



Bi-directional Reflectance Distribution Function

- Perfectly diffuse or lambertian surface has constant BRDF;

  Power reflected per unit area per solid angle =

  BRDF X power arriving per unit area X $\cos(\theta_s)$

- BRDF measurements/data are used to:
  - Calculate the amount of light or energy scattered by specific surfaces in critical applications
    - Example -- sunshield
  - Evaluate or monitor the condition of a surface with respect to contamination or roughness
    - Example -- optics (mirrors)
  - Determines specularity of surfaces for special cases
  - Calculate solar pressure

Types of Thermal Control Coatings

- **Paints** (Z93P, Z306, AZ93, Z93-C55, AZWLA2, Z276, Z307, etc.…)
- **Metals** (Al, Ag, Au, Ni, Stainless Steel, Cu, Mg, Ti, etc…)
- **Sheet Films** (Kapton®, Ge/Black Kapton®, Black Kapton®, Teflon (FEP), etc…)
- **Tapes** (Ag/FEP, Al/FEP, Al/Kapton®, Al Foil, Kapton®, Black Kapton® etc…)
- **Vacuum Deposited Coatings** [Evaporated/Sputtered]
  - **Metals** (Al, Ag, Au, Ti, Ge, Cr, Ni, etc…)
  - **Dielectrics** (Al_2O_3, SiO_x, CCAg, CCAl, Dark Mirror, etc…)
- **Conductive Coatings** (ITO, ATO, Ge, Z93-C55, Z307, etc…)
- **Anodized Aluminum** (Black, Hard, Clear, Plain, etc…)
- **Chemical Conversion** (Irridite, Alodine, etc…)
- **Optical Surface Reflectors** [OSR]
- **Solar Cells**

References

- “Thermal Radiative Properties Coatings”, Y.S. Touloukian, D. P. DeWitt, R. S. Hernicz; Thermophysical Properties of Matter, Volume 9; Pages 1a – 50a, IFI/Plenum, New York-Washington, 1972, (Introduction to Volumes 7, 8 and 9).
- “Spacecraft Thermal Control Coatings References”, NASA/TP-2005-212792, by Lonny Kauder, December 2005.